

Analysis of Materials for MEBT Absorber

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V2, Updated 3-7-2012
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Abstract: Neutron yields from copper and molybdenum MEBT absorber are compared.

Input data

The present favorite material is for the MEBT absorber is TZM alloy:

Ti 0.55% Max
Zr 0.12% Max
Mo Balance

The beam parameters: 2.1 MeV H-, 10 mA CW.

Base Data

Database for reactions:

<http://nndc.bnl.gov> → Q-value Calculator

Data for **Mo**:

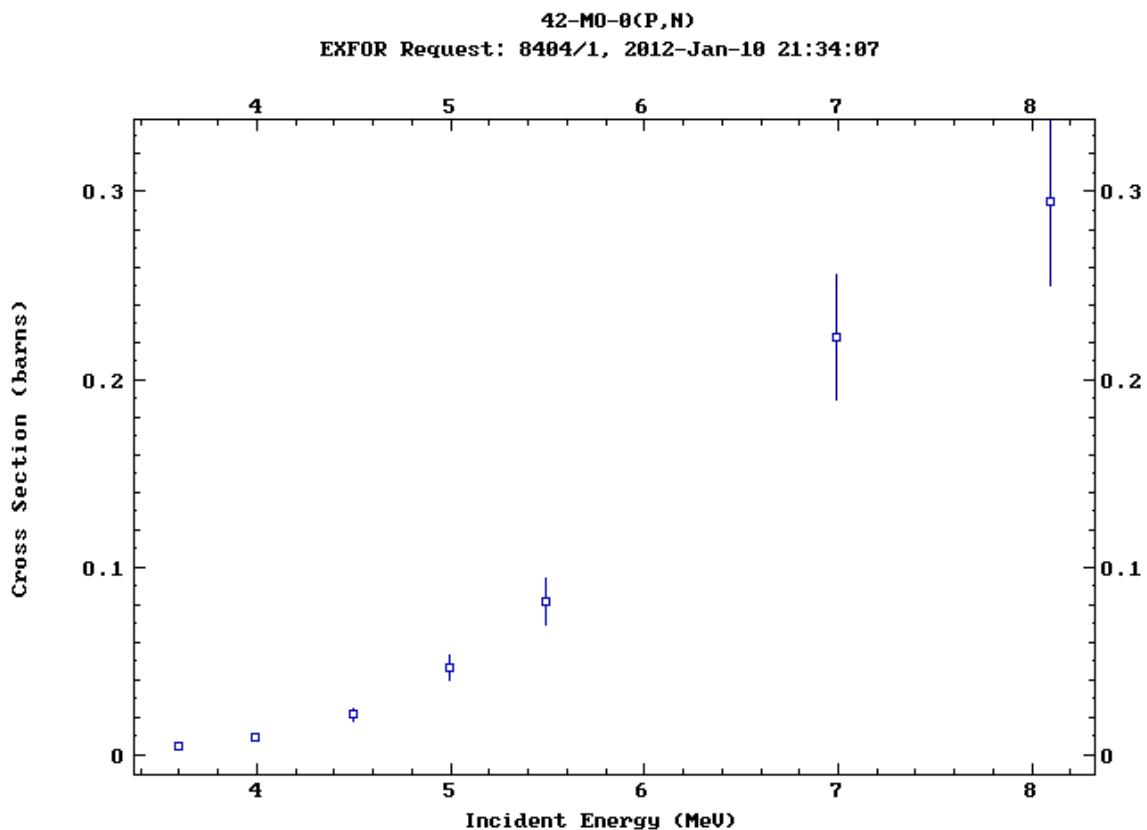
Isotope	Abundance,%	Reaction	Threshold, MeV
⁹⁸ Mo	24.13	⁹⁸ Mo (pn) ⁹⁸ Tc	2.492
⁹⁶ Mo	16.68	⁹⁶ Mo (pn) ⁹⁶ Tc	3.795
⁹⁵ Mo	15.92	⁹⁵ Mo (pn) ⁹⁵ Tc	2.499
⁹² Mo	14.84	⁹² Mo (pn) ⁹² Tc	8.748
¹⁰⁰ Mo	9.63	¹⁰⁰ Mo (pn) ¹⁰⁰ Tc	0.960
		¹⁰⁰ Tc (pn) ¹⁰⁰ Ru	0.0
		¹⁰⁰ Ru (pn) ¹⁰⁰ Rh	4.462
⁹⁷ Mo	9.55	⁹⁷ Mo (pn) ⁹⁷ Tc	1.114
		⁹⁷ Tc (pn) ⁹⁷ Ru	1.910
		⁹⁷ Ru (pn) ⁹⁷ Rh	4.350
⁹⁴ Mo	9.25	⁹⁴ Mo (pn) ⁹⁴ Tc	5.092

So, isotopic composition of residual:

Isotope	Abundance,%	Final Isotope
⁹⁸ Mo	24.13	⁹⁸ Mo
⁹⁶ Mo	16.68	⁹⁶ Mo
⁹⁵ Mo	15.92	⁹⁵ Mo
⁹² Mo	14.84	⁹² Mo
¹⁰⁰ Mo	9.63	→ ¹⁰⁰ Tc → ¹⁰⁰ Ru
⁹⁷ Mo	9.55	→ ⁹⁷ Tc → ⁹⁷ Ru
⁹⁴ Mo	9.25	⁹⁴ Mo

Database for cross sections:

<http://www.nndc.bnl.gov/exfor/exfor00.htm>



```
#ZView-data-copy: 10-Jan-2012 21:34:07
=====
#
#name: 42-MO-0(P,N),,SIG
#X.axis: Incident Energy
#Y.axis: Cross Section
#wdata: 3
#ldata: 7
#data...
#
#          X          Y      +-dY # Comments...
#     MeV      barns    barns # Year,Author(s)    ## EXFOR-ID
3.6      0.005  0.00075 # 1959,R.D.Albert  ## T0130015
4.0      0.01   0.0015  # 1959,R.D.Albert  ## T0130015
4.5      0.022  0.0033  # 1959,R.D.Albert  ## T0130015
5.0      0.047  0.00705 # 1959,R.D.Albert  ## T0130015
5.5      0.082  0.0123  # 1959,R.D.Albert  ## T0130015
7.0      0.223  0.03345 # 1959,R.D.Albert  ## T0130015
8.1      0.295  0.04425 # 1959,R.D.Albert  ## T0130015
//
```

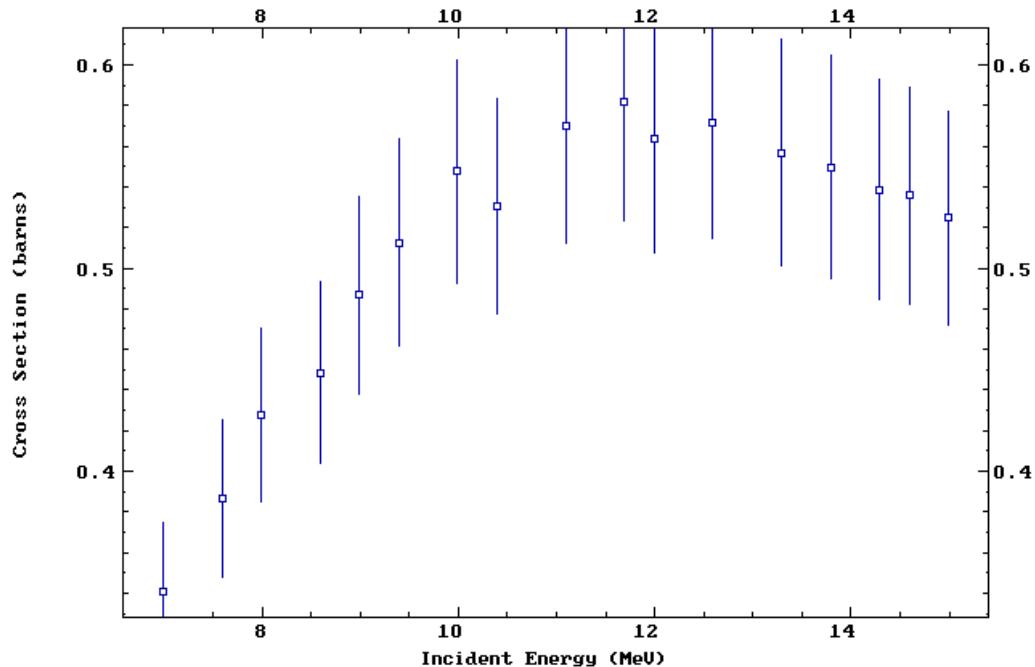
Data for **Ti**:

Isotope	Abundance, %	Reaction	Threshold, MeV
⁴⁸ Ti	73.80	⁴⁸ Ti (pn) ⁴⁸ V	4.895
⁴⁶ Ti	8.00	⁴⁶ Ti (pn) ⁴⁶ V	8.005
⁴⁷ Ti	7.30	⁴⁷ Ti (pn) ⁴⁷ V	3.792
⁴⁹ Ti	5.50	⁴⁹ Ti (pn) ⁴⁹ V	1.413
		⁴⁹ V (pn) ⁴⁹ Cr	3.479
⁵⁰ Ti	5.40	⁵⁰ Ti (pn) ⁵⁰ V	3.048

So, isotopic composition of residual:

Isotope	Abundance, %	Final Isotope
⁴⁸ Ti	73.80	⁴⁸ Ti
⁴⁶ Ti	8.00	⁴⁶ Ti
⁴⁷ Ti	7.30	⁴⁷ Ti
⁴⁹ Ti	5.50	→ V
⁵⁰ Ti	5.40	⁵⁰ Ti

22-TI-0(P,N)
EXFOR Request: 8403/1, 2012-Jan-10 21:27:16



```

#ZVVView-data-copy: 10-Jan-2012 21:27:16
=====
#
#name: 22-TI-0(P,N),,SIG
#X.axis: Incident Energy
#Y.axis: Cross Section
#wdata: 3
#ldata: 17
#data...
#      X          Y      +-dY # Comments...
#    MeV        barns      barns # Year,Author(s)    ## EXFOR-ID
    7          0.341     0.0341 # 1967,G.Chodil+ ## C0693003
   7.6         0.387     0.0387 # 1967,G.Chodil+ ## C0693003
    8          0.428     0.0428 # 1967,G.Chodil+ ## C0693003
   8.6         0.449     0.0449 # 1967,G.Chodil+ ## C0693003
    9          0.487     0.0487 # 1967,G.Chodil+ ## C0693003
   9.4         0.513     0.0513 # 1967,G.Chodil+ ## C0693003
   10         0.548     0.0548 # 1967,G.Chodil+ ## C0693003
  10.4        0.531     0.0531 # 1967,G.Chodil+ ## C0693003
  11.1        0.57      0.057  # 1967,G.Chodil+ ## C0693003
  11.7        0.582     0.0582 # 1967,G.Chodil+ ## C0693003
   12         0.564     0.0564 # 1967,G.Chodil+ ## C0693003
  12.6        0.572     0.0572 # 1967,G.Chodil+ ## C0693003
  13.3        0.557     0.0557 # 1967,G.Chodil+ ## C0693003
  13.8        0.55      0.055  # 1967,G.Chodil+ ## C0693003
  14.3        0.539     0.0539 # 1967,G.Chodil+ ## C0693003
  14.6        0.536     0.0536 # 1967,G.Chodil+ ## C0693003
   15         0.525     0.0525 # 1967,G.Chodil+ ## C0693003
// -----

```

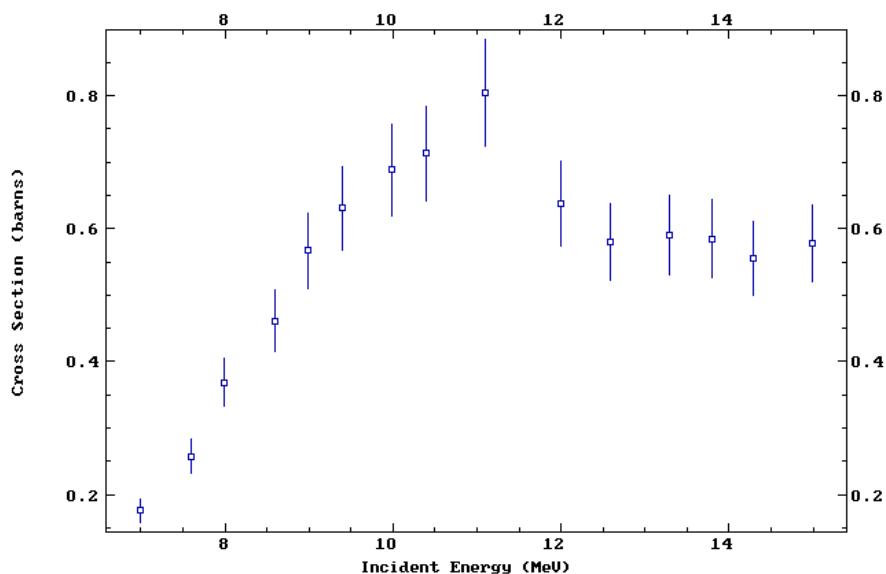
Data for **Zr**:

Isotope	Abundance,%	Reaction	Threshold, MeV
⁹⁰ Zr	51.45	⁹⁰ Zr (pn) ⁹⁰ Nb	6.971
⁹⁴ Zr	17.38	⁹⁴ Zr (pn) ⁹⁴ Nb	1.703
		⁹⁴ Nb (pn) ⁹⁴ Mo	0.0
		⁹⁴ Mo (pn) ⁹⁴ Tc	5.092
⁹² Zr	17.15	⁹¹ Zr (pn) ⁹¹ Nb	2.818
⁹¹ Zr	11.22	⁹¹ Zr (pn) ⁹¹ Nb	2.063
		⁹¹ Nb (pn) ⁹¹ Mo	5.264
⁹⁶ Zr	2.80	⁹⁶ Zr (pn) ⁹⁶ Nb	0.628
		⁹⁶ Nb (pn) ⁹⁶ Mo	0.0
		⁹⁶ Mo (pn) ⁹⁶ Tc	3.795

So, isotopic composition of residual:

Isotope	Abundance, %	Final Isotope
^{90}Zr	51.45	^{90}Zr
^{94}Zr	17.38	$\rightarrow^{94}\text{Nb} \rightarrow^{94}\text{Mo}$
^{92}Zr	17.15	^{92}Zr
^{91}Zr	11.22	$\rightarrow^{91}\text{Nb}$
^{96}Zr	2.80	$\rightarrow^{96}\text{Nb} \rightarrow^{96}\text{Mo}$

40-ZR-0(P,N)
EXFOR Request: 8485/1, 2012-Jan-10 21:36:24



```
#ZVVView-data-copy: 10-Jan-2012 21:36:24
=====
#
#name: 40-ZR-0(P,N),,SIG
#X.axis: Incident Energy
#Y.axis: Cross Section
#wdata: 3
#ldata: 15
#data...
#
#      X          Y          +-dY    # Comments...      ## EXFOR-ID
#      MeV        barns      barns   # Year,Author(s)
#      7           0.177     0.0177  # 1967,G.Chodil+  ## C0693006
#      7.6         0.258     0.0258  # 1967,G.Chodil+  ## C0693006
#      8           0.370     0.037   # 1967,G.Chodil+  ## C0693006
#      8.6         0.462     0.0462  # 1967,G.Chodil+  ## C0693006
#      9           0.568     0.0568  # 1967,G.Chodil+  ## C0693006
#      9.4         0.632     0.0632  # 1967,G.Chodil+  ## C0693006
#      10          0.690     0.069   # 1967,G.Chodil+  ## C0693006
#      10.4        0.714     0.0714  # 1967,G.Chodil+  ## C0693006
#      11.1        0.805     0.0805  # 1967,G.Chodil+  ## C0693006
```

```

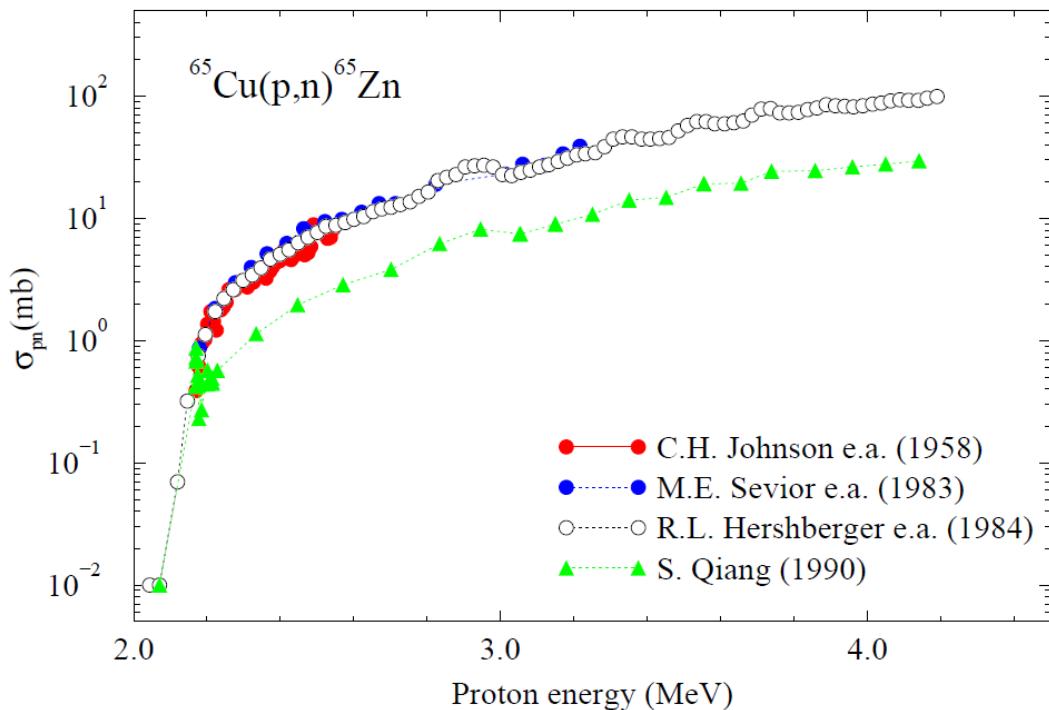
      12          0.639      0.0639  # 1967,G.Chodil+    ## C0693006
     12.6         0.581      0.0581  # 1967,G.Chodil+    ## C0693006
     13.3         0.591      0.0591  # 1967,G.Chodil+    ## C0693006
     13.8         0.586      0.0586  # 1967,G.Chodil+    ## C0693006
     14.3         0.557      0.0557  # 1967,G.Chodil+    ## C0693006
      15          0.579      0.0579  # 1967,G.Chodil+    ## C0693006
//
```

Data for Cu:

Isotope	Abundance, %	Reaction	Threshold, MeV
^{63}Cu	69.17	$^{63}\text{Cu}(\text{pn})\ ^{63}\text{Zn}$	4.215
^{65}Cu	30.83	$^{65}\text{Cu}(\text{pn})\ ^{65}\text{Zn}$	2.167

So, isotopic composition of residual:

Isotope	Abundance, %	Final Isotope
^{63}Cu	69.17	^{63}Cu
^{65}Cu	30.83	^{65}Cu



```

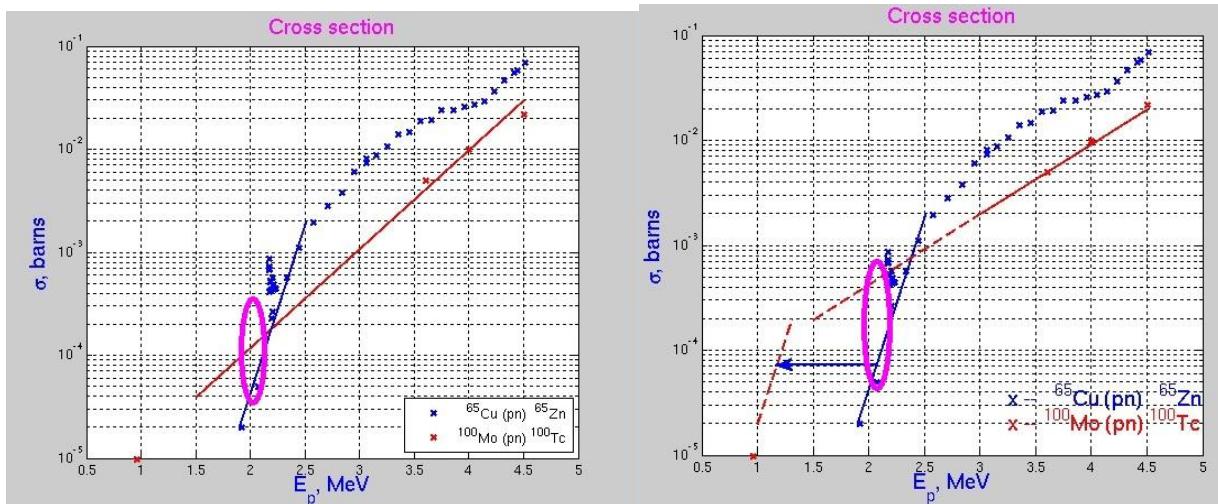
#ZVView-data-copy: 18-Jan-2012 23:36:28
=====
#
#name: 29-CU-0(P,N),,SIG
#X.axis: Incident Energy
#Y.axis: Cross Section
#wdata: 3
#ldata: 84
#data...
#
#      X          Y          +-dY    # Comments...
#      MeV        barns     barns   # Year,Author(s)      ## EXFOR-ID
#      1.917      2e-5      7.4e-7  # 1990,S.Qiang    ## C0739002
#      1.927      0          0        # 1990,S.Qiang    ## C0739002
#      2.07       5e-5      9.15e-7 # 1990,S.Qiang    ## C0739002
#      2.07       1e-5      7.34e-7 # 1990,S.Qiang    ## C0739002
#      2.169      0.00042   1.6212e-5 # 1990,S.Qiang    ## C0739002
#      2.17       0.00068   1.6184e-5 # 1990,S.Qiang    ## C0739002
#      2.171      0.00073   1.4965e-5 # 1990,S.Qiang    ## C0739002
#      2.171      0.00087   1.479e-5  # 1990,S.Qiang    ## C0739002
#      2.172      0.0007    1.246e-5  # 1990,S.Qiang    ## C0739002
#      2.175      0.00052   8.684e-6  # 1990,S.Qiang    ## C0739002
#      2.178      0.00043   6.622e-6  # 1990,S.Qiang    ## C0739002
#      2.178      0.00023   5.221e-6  # 1990,S.Qiang    ## C0739002
#      2.185      0.00044   5.236e-6  # 1990,S.Qiang    ## C0739002
#      2.185      0.00027   4.239e-6  # 1990,S.Qiang    ## C0739002
#      2.202      0.00057   4.275e-6  # 1990,S.Qiang    ## C0739002
#      2.202      0.00044   3.784e-6  # 1990,S.Qiang    ## C0739002
#      2.214      0.00046   3.312e-6  # 1990,S.Qiang    ## C0739002
#      2.214      0.00049   3.381e-6  # 1990,S.Qiang    ## C0739002
#      2.214      0.00045   3.285e-6  # 1990,S.Qiang    ## C0739002
#      2.214      0.00046   3.266e-6  # 1990,S.Qiang    ## C0739002
#      2.214      0.00045   3.24e-6   # 1990,S.Qiang    ## C0739002
#      2.229      0.00057   3.192e-6  # 1990,S.Qiang    ## C0739002
#      2.334      0.00113   3.955e-6  # 1990,S.Qiang    ## C0739002
#      2.447      0.00196   5.292e-6  # 1990,S.Qiang    ## C0739002
#      2.57       0.00287   8.897e-6  # 1990,S.Qiang    ## C0739002
#      2.701      0.0038    1.026e-5  # 1990,S.Qiang    ## C0739002
#      2.834      0.00616   1.2936e-5 # 1990,S.Qiang    ## C0739002
#      2.946      0.00816   1.9584e-5 # 1990,S.Qiang    ## C0739002
#      3.053      0.0074    1.85e-5   # 1990,S.Qiang    ## C0739002
#      3.054      0.00742   1.855e-5  # 1990,S.Qiang    ## C0739002
#      3.149      0.00893   2.5004e-5 # 1990,S.Qiang    ## C0739002
#      3.149      0.00892   2.4976e-5 # 1990,S.Qiang    ## C0739002
#      3.251      0.01071   2.7846e-5 # 1990,S.Qiang    ## C0739002
#      3.351      0.01409   3.0998e-5 # 1990,S.Qiang    ## C0739002
#      3.452      0.01475   3.245e-5  # 1990,S.Qiang    ## C0739002
#      3.554      0.01907   3.6233e-5 # 1990,S.Qiang    ## C0739002
#      3.554      0.01913   3.6347e-5 # 1990,S.Qiang    ## C0739002
#      3.655      0.01939   5.2353e-5 # 1990,S.Qiang    ## C0739002
#      3.739      0.02415   5.796e-5  # 1990,S.Qiang    ## C0739002
#      3.858      0.02444   5.8656e-5 # 1990,S.Qiang    ## C0739002
#      3.959      0.02637   6.0651e-5 # 1990,S.Qiang    ## C0739002
#      4.05       0.02777   6.1094e-5 # 1990,S.Qiang    ## C0739002
#      4.141      0.02952   6.4944e-5 # 1990,S.Qiang    ## C0739002
#      4.231      0.03678   6.9882e-5 # 1990,S.Qiang    ## C0739002
#      4.323      0.04715   8.0155e-5 # 1990,S.Qiang    ## C0739002
#      4.323      0.04734   8.0478e-5 # 1990,S.Qiang    ## C0739002

```

4.323	0.04719	8.0223e-5	# 1990, S.Qiang	## C0739002
4.412	0.05565	0.00012243	# 1990, S.Qiang	## C0739002
4.44	0.05876	0.0001234	# 1990, S.Qiang	## C0739002
4.44	0.05875	0.00012337	# 1990, S.Qiang	## C0739002
4.51	0.06964	0.00013928	# 1990, S.Qiang	## C0739002

Analysis

1. In the production of neutrons it can be neglected of the contribution for all reactions except $^{100}\text{Mo}(\text{pn})^{100}\text{Tc}$ and $^{97}\text{Mo}(\text{pn})^{97}\text{Tc}$. Overall abundance for these isotopes is $\eta \leq 20\%$.
2. For these reactions it is possible to compare their cross sections with cross section of the reaction $^{65}\text{Cu}(\text{pn})^{65}\text{Zn}$ ($\eta \leq 30\%$):



3. From these plots one can find (using different approaches) that for $E_p \approx 2.1 \text{ MeV}$ the cross sections for Mo larger than for Cu from 2 to 8 times:

$$\sigma \approx \begin{cases} 0.06 \text{ mb} & \text{for Cu;} \\ 0.12 - 0.50 \text{ mb} & \text{for Mo.} \end{cases}$$

4. Let's calculate the neutron yield per proton from 1 cm^3 of the material:

$$N_n = 6.02 \cdot 10^{23} \frac{\rho \sigma}{A} \eta,$$

For input data

	A	$\rho, \text{ g} \cdot \text{cm}^{-3}$	$\sigma, \text{ mb}$	$\eta, \%$
Cu	63.54	8.94	0.06	30
Mo	95.94	10.28	0.12 ÷ 0.50	20

one has the following results:

$$N_n \approx \begin{cases} 1.5 \cdot 10^{-6} \text{ p/p} & \text{for Cu;} \\ (3-12) \cdot 10^{-6} \text{ p/p} & \text{for Mo.} \end{cases}$$

Conclusions

1. Despite the fact that the beam energy is below of the threshold of reactions induced in copper, the neutrons will be produced by the beam with the absorber (“tunnel effect”).
2. Some reactions with molybdenum have thresholds below the beam energy, so that these reactions will lead to the neutron production.
3. In case of the molybdenum absorber, the number of neutrons can be an order of magnitude greater than for copper.

Additional Questions

1. Dose levels due to these neutrons?
2. Comparison of this neutron flux and flux from interaction (accident and operation conditions) between the beam and PXIE device as a whole?